

Geospatial analysis and Remote Sensing  
From airplanes and Satellites  
For Cultural Resources Management

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## INTRODUCTION

Cultural resource management consists of research to identify, evaluate, document and assess cultural resources, planning to assist in decision-making, and stewardship to implement the preservation, protection and interpretation of these decisions and plans. Traditionally, archaeological methods used to accomplish these goals are time consuming, labor intensive, and expensive. Moreover, they rely on sampling strategies that can lead to an inaccurate assessment of cultural resources.

One technique that may be useful in cultural resource management archaeology is remote sensing. It is the acquisition of data and derivative information about objects or materials (targets) located on the Earth's surface or in its atmosphere by using sensor mounted on platforms located at a distance from the targets to make measurements on interactions between the targets and the electromagnetic radiation (Lyons and Avery 1977; Ebert and Lyons 1983; Short, 1982, Giardino and Thomas 2002.). Included in this definition are systems that acquire imagery by photographic methods and digital multispectral sensors, which are the core of the modern remotes sensing industry. Today, data collected by digital multispectral sensors on aircraft and satellite platforms play a prominent role in many earth science applications, including land cover mapping, geology, soil science, agriculture, forestry, water resource management, urban and regional planning, and environmental assessments (Lillesand and Kiefer 1994). These systems often employ sensors that record discreet segments of electromagnetic energy well beyond film, such as thermal infrared. Such systems can rapidly accumulate detailed information on ground targets.

Inherent in the analysis of remotely sensed data is the use of computer-based image processing techniques, which enhance the interpretability of remotely sensed data. Desktop computing power has become less expensive and more powerful, and image processing software has become more accessible, more user-friendly and fully capable of even the most sophisticated processing of digital data, like that collected during remote sensing missions. Geographical information systems (GIS), systems designed for collecting, managing, and analyzing spatial information, are also useful in the analysis of remotely sensed data. A GIS can be used to integrate diverse types of spatially referenced digital data, including remotely sensed data in raster format and supplementary vector map data.

In archaeology, these tools have been used in various ways to aid in cultural resource projects. For example, they have been used to predict the presence of archaeological resources using modern environmental indicators. Remote sensing techniques have also been used to directly detect the presence of unknown sites based on the impact of past occupation on the Earth's surface. Additionally, remote sensing has been used as a mapping tool aimed at delineating the boundaries of a site or mapping previously unknown features. All of these applications are pertinent to the goals of site discovery and assessment in cultural resource management.

## REMOTE SENSING PRINCIPLES

Black and white aerial photography has been used for some time for archaeological reconnaissance. It is essentially a broad band, panchromatic remote sensing technique covering the visible portion of the electromagnetic spectrum (EMS, figure 1). Aerial photographs may be scanned and given geographic coordinates or downloaded as georeferenced digital data to be included as a GIS data layer. In Britain, particularly, aerial photography is used as a primary technique of site discovery and site mapping in cultural resource mapping.

Archaeological features may be apparent in aerial photography as variations in soil color, moisture patterning, frost and snow marks, and crop marks (Scollar 1990:37-51). Several works offer explanations of how archaeological resources can be detected in this way (Hampton 1974, Jones 1979, Riley 1979, Allen 1984, Stanjek 1995).

The visibility of archaeological features as soil marks may be related to soil chemistry, organic material content, and soil texture (Scollar 1990:37). These characteristics alter the reflectance (possible footnote: reflectance is defined as the ration of reflected radiant energy to the irradiant solar energy and is commonly expressed as a percentage, Short, 1982:25) values of the features. One cause for this is that cultural activities will sometimes leave behind an increased amount of chemicals, such as iron oxides. Iron oxides tend to redden the soil color. Organic material also has distinct chemical properties. In this case, the soil color is darkened.

In addition, archaeological features that cause a soil texture variation may alter reflectance values. In general, reflectance increases with decreasing particle size (Allen 1984:190). Soil texture differences may be visible for several types of features. Cultural landscape modifications, such as mound construction or fill episodes, may leave a soil layer distinguishable from surrounding soils. Likewise, pits may leave perceivable differences due to mixing of topsoil. Buried sites have an effect on soil phenomenology that is observable without the ability to penetrate the soil. Any feature that either drains water better than the surrounding area or retains water more than the surrounding area can provide visual evidence on the remote sensing imagery (Ouachita site mounds).

Soil texture differences can also be developed as damp marks (Allen 1984:68). The diameter of micropores in clays is about 2  $\mu\text{m}$ , while the diameter in sandy soil ranges from 63  $\mu\text{m}$  to 2000  $\mu\text{m}$  (Stanjek and Fabinder 1995:95). Therefore, fine-grained soils, such as clays, will drain less moisture than larger grained soils. Thus, if an archaeological feature leaves soil texture variation, differential moisture patterning may result if conditions are adequate (insert figure from Taylor mounds showing D-ring feature in thermal ATLAS channel).

Rainfall levels preceding photograph acquisition is very important in the visibility of damp marks. In some cases, soil marks may be visible for only a few days. In general, they may show best when soils are drying out (Allen 1984:68, Drass 1989:83). One project found that the second day after a rain was the best for soil mark development. Wilson (1982:50) has remarked that, as a general rule, soils should not be excessively wet or dry for best development.

Also, plowing plays a role in making subsurface features detectable as soil marks. Plowing episodes bring up a sample of subsurface features, including archaeological materials, each time it passes over an area (Wilson 1982:41). Moreover, the lower materials are usually turned over so that they are most visible (Riley 1987:21). Soil marks may be particularly prominent after fallow fields have been plowed (Drass 1989:84). It should be noted, however, that materials might be transported from their original positions by the plow (Wilson 1982:42). Eventually, repeated plowing may render the ground surface homogeneous and cause marks to disappear.

Frost and snow marks relating to archaeological features may be visible due also to soil texture differences (Riley 1987:21). This is primarily the result of thermal mechanisms. The timing is critical, however, since they are often visible for only a few hours after sunrise (Scollar 1990:49). Frost and snow marks, of course, may rarely be applicable in the warmer portions of the United States.

Crop marks may also reveal the location of archaeological features when the ground is covered by vegetation. Crop marks are caused by variations in vigor, which may be visible as differences in plant height, leaf area, or plant color (Jones 1979:657). Depending on the type of feature, crop vigor may be enhanced or worsened by buried archaeological features (figure 2). Features that retain

water, such as ditches, will often enhance plant and growth. On the other hand, features that inhibit root penetration, such as buried walls, will produce vegetation above them that are less healthy than the surrounding area.

One factor in the visibility of meaningful crop marks is the type of plant present. Plant species vary widely in their growth cycle and buried archaeological features may only be apparent at certain stages (Riley 1979:30). For example, a positive mark may result due to increased transpiration of the vegetation, causing early development (Stanjek and Fabinder 1995:100). Later in the cycle, the crop marks may not be visible at all. However, the crops that exhibited enhanced growth will use up water faster and may ripen faster (Riley 1979:31). Thus, the crop marks would once again be visible.

Crop marks have often been observed in cereal crops, including barley, wheat, oats, and rye (Jones 1979:656-657, Allen 1984:75, Riley 1987:31). These crops are very responsive to variation in soil moisture. Cereals may reveal archaeological features as variations in development, germination, plant height, and ripening (Riley 1987:33). However, observations of these crops are prevalent because these are the common crops in Great Britain. Grasses have also shown crop marks, but they are generally less responsive to soil differences than cereal crops (Riley 1987:30). Allen has noted that grasses are particularly sensitive to short-term changes in ground moisture and this may cause the disappearance of meaningful crop marks (Allen 1984:75). Indeed, Riley (1979:29) has posited that grasses are not helpful for archaeologists. Other crops have also revealed archaeological features as crop marks, although they are less common. Root crops, such as turnips, potatoes, and beets, vary in their ability to show markings. Generally, those with deep roots are better at developing markings (Wilson 1982:61). Weeds have been observed to show crop marks in some cases (Wilson 1982:64). However, chemical treatments inhibit mark development in weeds (Wilson 1982:30). Regardless of the type of plant present, homogeneous vegetation cover is advantageous (Jones 1979:656).

Long-term weather patterns are very critical in the visibility of vegetation marks. Droughts often produce the most defined marks (Stanjek and Fabinder 1995:91). The experiments of Jones (1979) have indicated that a soil moisture deficit can trigger crop marks. The available water by volume is a function of soil particle size and thus soil texture is an important factor (Jones 1979:662). For example, Riley (1979:31) has noted that sandy soil frequently produces crop marks, while clayey soil does not. Also, moisture deficits are closely related to the root depth, which is determined by the plant species (Jones 1979:662). In some cases, rapid periods of rainfall have also been observed to cause crop marks (Drass 1989:83).

The timing of plowing episodes is an important factor, although less than with soil marks. In some cases, freshly plowed soils may enhance crop mark visibility (Stanjek and Fabinder 1995:92). However, plowing patterns can sometimes appear similar to archaeological patterns.

The use of color and color infrared photography has further increased the amount of information that can be gathered over ground targets. In terms of display, the human eye can distinguish more variations of color tones than gray tones. Therefore, more subtle patterns can be noticeable in color photographs than black and white. In addition, color infrared film is sensitive to the wavelengths just beyond the visible spectrum, which are highly sensitive to soil moisture and vegetation health.

Like film-based systems, multispectral digital sensors operate by sensing electromagnetic energy, which propagates through space in the form of a wave. All objects reflect and absorb various wavelengths of electromagnetic energy when at temperatures above absolute zero. For example, a leaf strongly reflects energy in the infrared area and moderately reflects energy in the green area, while it absorbs energy in the blue and red areas (Limp 1992:186). The human eye is a

sensor that detects electromagnetic energy from approximately .4  $\mu\text{m}$  to .7  $\mu\text{m}$  in wavelength. Since green energy is within the visible spectrum, we can detect a leaf with our eyes. However, the entire range of electromagnetic energy is well beyond our visible range. A leaf cannot be seen in the near infrared range because our eye cannot detect this wavelength.

Remote sensing instruments, normally radiometers and scanners, can be designed to sense energy beyond the range of the human eye (Lillesand and Kiefer 2000:9). The electromagnetic energy of a ground target is directed to an array of detectors by some optical device, where it is absorbed. The size of the area sensed is called the instantaneous field of view (IFOV), which is usually expressed as an angle (Lillesand and Kiefer 1994:310). The intensity of this energy received is subsequently converted into a digital value. Once in digital form, the values (also known as Brightness values (BV)) are stored in a matrix with each value representing an area of the earth's surface and these can be viewed as a raster image.

Unlike active remote sensors like Radar and Lidar that provide their own energy, passive remote sensors collect energy that is naturally occurring. This energy may be reflected energy resulting from the interaction of solar energy and the earth's features. Reflected energy makes up the visible and near infrared portion of the EMS. Alternatively, the energy may be emitted from a target as thermal infrared energy.

Remote sensing systems are often multispectral, which means they detect energy across discrete segments of the electromagnetic spectrum (EMS). The particular segment of the EMS sensed is determined by the materials used in each detector in an array. Remotely sensed targets are wavelength dependent, which means that, even within a given feature type, the proportion of reflected, transmitted, and absorbed energy will vary at different wavelengths. Thus, two features that are identical at one wavelength may be different in another area of the EMS (cf. Lillesand and Kiefer, 2000: 13). Each type of material on the Earth has a characteristic response curve that varies when one views the energy along the EMS. Therefore remote sensing can be extremely useful for determining ground cover.

Furthermore, multispectral bands are variably sensitive to target phenomena (Lillesand and Kiefer 1994). The Landsat Thematic Mapper sensor is a good example. Landsat band 1 (.45-.50  $\mu\text{m}$ ) covers the blue portion of the visible spectrum and can discriminate between soil and vegetation. Band 2 (.50 - .57  $\mu\text{m}$ ) covers the green area and is excellent at assessing plant health. The red Band 2 (.61-.70  $\mu\text{m}$ ) can be used to determine chlorophyll absorption. Bands 3 (.70 - .90  $\mu\text{m}$ ) senses near infrared energy and can determine vegetation type, vigor, biomass content, and soil moisture. The mid-infrared band 5 (1.55-1.75 microns) is sensitive to the turgidity or amount of water in plants. Such information is useful in crop drought studies and in plant vigor investigations. In addition, this is one of the few bands that can be used to discriminate between clouds, snow, and ice, so important in hydrologic research. On the other hand, the mid-infrared band 6 (2.08-2.35 microns) is an important band for the discrimination of geologic rock formations. It has been shown to be particularly effective in identifying zones of hydrothermal alteration in rocks, vegetation stress analysis, and for soil mapping. The thermal infrared band (10.4-12.5 microns) measures the amount of infrared radiant flux emitted from surfaces and is useful for locating geothermal activity thermal inertia mapping for geologic investigations, vegetation classification, vegetation stress analysis, and soil moisture studies (Jensen 1986:34).

When describing digital remote sensing systems, it is helpful to characterize several types of resolution. Spatial resolution is the ability of an imaging system to record detail or the size of the minimum pixel resolved by the sensor. It is also referred to as ground resolution since it describes an area of the earth's surface. This quantity determines an instrument's ability to resolve different

size parcels (or pixels) of land or water. Since sensors record a fixed number of digital values for an IFOV, spatial resolution is finite. Thus, the IFOV and array size are closely related to the spatial resolution. However, it also means that the dwell time over a target and thus the amount of energy focused on the detector is less (Lillesand and Kiefer 1994:312).

Sensors currently in use, or nearing deployment, offer significantly finer spatial resolutions than were previously available. Low spatial resolution sensors, such as the GOES (Geostationary Operational Environmental Satellites), have high orbits and relatively coarse ground resolutions (about 1 km pixels in the visible bands). They can image an entire hemisphere of the Earth and are used widely as weather satellites. Sensors with moderate spatial resolutions, like the Landsat MSS and TM instruments with ground resolutions between 79 m and 30 m, provide regional coverage and have been used extensively in archaeology for landscape analysis (Limp 1993; Custer et al 1987; Johnson et al. 1991) and predictive modeling. High spatial resolution sensors are becoming much more common and collect data useful at the local level. These include the new French SPOT-5 (5 meter panchromatic and 10 meter multispectral), the Indian Remote Sensing Program's IRS-1D (5.8 m panchromatic), Space Information's SPIN-2 (2 meter panchromatic), formerly classified Russian satellites (approximately 1 m panchromatic), Space Imaging's IKONOS (4 meter multispectral and 1 m panchromatic), and Digital Globe's QuickBird (). Paired with new techniques of image analysis, this technology may make the direct detection of archaeological sites a realistic goal.

The ability of passive remote sensing instruments to collect energy in specific wavelengths defines the sensor's spectral resolution and thereby its ability to discriminate between objects based on the materials' spectral response curves or patterns. Within each band of a sensor, energy is undifferentiated and a target's spectral properties are indistinguishable. Thus the size and number of bands that a sensor utilizes determines its spectral resolution (Limp 1992:186). A sensor with a higher spectral resolution can differentiate between energy sources better than a sensor with a lower spectral resolution. However, the available energy is a limiting factor on spectral resolution because, as sensor bands become narrower, detectors collect less energy.

Radiometers and scanners that are able to record energy in relatively broad bands, normally defined as 10  $\mu\text{m}$  (micrometers or  $10^{-6}$  meters) wide are denoted as multispectral scanners. Landsat MSS, TM, ETM, the SPOT sensors, the IRS sensors, and those mounted on the newer commercial systems like IKONOS and QuickBird are multispectral.

Passive sensors that collect energy in narrow bands, defined normally as about 10 nm (nanometers or  $10^{-9}$  meters) wide are known as hyperspectral sensors. The newer hyperspectral sensors, such as Hyperion, have only recently been deployed in orbit. However, they have flown on research aircrafts for many several years. NASA's Jet Propulsion Laboratory operates an instrument called the Airborne Visible InfraRed Imaging Spectrometer (AVIRIS). This sensor is flown aboard a modified U-2 airplane at an altitude of about 20,000 meters. Ground resolution varies with the altitude of the aircraft, but is generally 15-20 meters; the image swath width is about 11 km. AVIRIS measures surface reflectance in 224 bands in the visible and near infrared portions of the spectrum (from 400-2500 nanometers). Each band is approximately 10 nanometers wide. The amount of data that the AVIRIS produces is prodigious; one flight line covering about a 10 x 11 km area on the ground produces a 140 megabyte image file. But in return, AVIRIS provides an extremely precise record of surface reflectance. The disadvantages include large data sets, platform instability requiring excessive pre-processing corrections. Where multispectral systems can distinguish broad differences between earth's many features, such as broad vegetation classes like hardwood and softwood forest types or tree genera, hyperspectral sensors can identify different tree species as well as more subtle aspects of a plant or soil, such as plant stress or soil mineralogy.

In addition to the improved spatial resolution of recent sensors, many offer much improved spectral resolutions, demonstrated by the trend toward hyperspectral radiometers. Also, newer orbiting sensors offer spectral resolutions that were in the past only available from flying sensors on airborne platforms.

Radiometric resolution corresponds to a sensor's ability to differentiate between amounts of radiation received (Limp 1992:186). Commonly, 8 bit data is used that corresponds to 256 values at a range of 0 to 255. However, digital sensors are not limited to this and there are examples of sensors that use 11 bit data, corresponding to 2048 values, or other amounts. This range of values determines a sensor's radiometric resolution. For example, 11 bit digital data has a higher radiometric resolution than 8 bit digital data. Generally, a higher radiometric resolution is advantageous. However, to successfully differentiate between amounts of radiation, more energy is necessary. The newer remote sensors typically have high radiometric resolutions.

Temporal resolution is also an important characteristic of a sensor. This refers to the revisit time of a satellite over a particular geographic location. Some sensors in the modern fleet of NASA's Earth Science satellites revisit specific locations twice daily. Others, like Landsat, return to the same locale every 16 days. Sensors mounted on aircraft have variable temporal resolutions since they can be deployed as needed.

Archaeological features may be detected using reflected energy bands of a multispectral sensor for the same reasons they are visible in aerial photographs. However, because the narrow spectral range of multispectral sensors makes each band sensitive to specific target phenomena, they have the potential of detecting much more subtle features. Also, the options are greater both in manipulating the data and in the capability of seeing electromagnetic energy beyond that detected with film. Work in the short wave infrared (SWIR, 1.55-2.55  $\mu\text{m}$ ) and the mid infrared (MIR, 3.35-4.20  $\mu\text{m}$ ) is now showing promise for detecting features of archaeological interest. Digital image processing techniques often vastly enhance the interpretability of remote imagery. Also, the ability of a display system like the computer screen to load a variety of bands in the RGB video guns provides added flexibility for interpretation.

Narrow-band imagery, properly calibrated and used in indices can assess plant vigor and plant stress. Specifically, the middle infrared region between 1,300 nanometers and 2,400 nanometers offers promise for this task because it is the main absorption bands for leaf water. Water-stressed plants have increased reflectance in this wavelength region. The narrow bands of hyperspectral sensors may further increase the utility of remote sensing in aiding in identifying sites by identifying plant health and stress.

Multispectral sensors can also be useful in archaeological applications by typing vegetation. The association of unique vegetation communities with geological, ecological and archaeological sites is well documented (Eleuterius and Otvos 1979; , Nanette and Leslie 1988, Penfound 2001; ). Past occupation, as mentioned already, can alter the chemical properties of the soil and certain plants may be more adapted to such conditions. When distinct ground cover is consistently associated with archaeological deposits, it may be possible to detect archaeological sites in remote imagery. Using this technique, it may be possible to identify likely site locations based on the co-occurrence of these materials.

One excellent example is the shell mounds and middens that are common in coastal Louisiana and Mississippi. Eleuterius and Otvos report that several species, including red mulberry, coral bean, and buckeyes, found in association with these features are calciophiles, whose presence is "favored and determined by the large amount of calcium" in clam shells. Shell mounds also support a variety of shrubs and woody vines and a number of herbs and grasses that are not found in the marsh. Conversely, the hard substrate formed by buried shells may stunt root development and

may show significant differences between on-site and off-site plants, significant enough to allow mapping of buried shell middens from aerial imagery. Also, oak trees may be markers of archaeological sites, particularly in the marshes, where sites are often the only ground elevated enough to support these trees. Like coastal Louisiana and Mississippi, other regions that exhibit a number of distinct surface characteristics, may be particularly well-suited to this approach. Furthermore, hyperspectral sensors may increase the effectiveness of plant species as discriminators of archaeological sites.

A series of vegetation variability indices can be determined using image processing techniques and a difference between the site and the surrounding area may be visible. It may be hypothesized that archaeological sites exhibit more variability in plant species than non-archaeological sites as a reflection of centuries of human activity, including collecting plants, firewood and canes. In the absence of drastic ecological changes, it may be postulated that these plants have continued to germinate and to flourish on specific sites. Indices of vegetation variability may provide the evidence for testing such hypotheses thereby providing practical methods for identifying sites in vegetated areas.

Besides reflected bands, some multispectral sensors can detect thermal infrared energy. Thermal infrared energy is emitted from an object, such as the earth, and thus operates quite differently than reflected energy bands. The phenomenon that makes thermal bands valuable is that target materials heat and cool variably. More specifically, the thermal behavior of a target is determined by several quantities, which include thermal conductivity, density, and specific heat. These determine how a material stores heat and how readily heat flows through it (Lillesand and Kiefer). In a layered earth, the thermal properties of each material and the subsurface thermal gradient are all relevant. A convenient measure, thermal inertia, can be derived from the aforementioned quantities and is inversely proportional to the response of the ground to thermal energy. Thermal inertia values for a number of common substances are shown in table 1.

By considering thermal inertia values, a very basic understanding of how an archaeological target will behave thermally can be gained. In the morning, as the heat is focused toward the ground, a subsurface feature may be detected as a positive or negative anomaly. For example, a buried feature, such as a pit, that traps moisture will result in a negative anomaly in the morning because moisture effectively lowers the thermal inertia of the pit feature. In the evening, this situation would be reversed since the thermal gradient would be from the ground to the atmosphere. Conversely, a feature that enhances drying would be visible as a positive anomaly in the morning and a negative anomaly in the evening. As with any prospection technique, archaeological features may be detected with thermal prospecting only if the physical properties of the feature differ enough to cause a visible contrast in the imagery. The use of long wavelengths such as thermal infrared has been used to identify soil and or vegetation anomalies that may indicate buried sites.

## IMAGE PROCESSING TECHNIQUES

Each digital image requires some preprocessing before the needed information can be extracted by the data. One such process involved the rectification of an image either to another image or to a map. The latter process produces images with planimetric characteristics that can be used as maps, similar to Digital Orthoquads. The second type of pre-processing that normally is required to properly extract information from remotely sensed data is radiometric correction, commonly referred to as atmospheric correction. Since not all the energy that reaches the sensors can be ascribed solely to the pixel of interest, a radiance measurement at the sensors needs to be



converted to a reflectance measurement. The process to do so is beyond the scope of this chapter, but several referenced are available that deal with the issue of atmospheric correction in depth. It is important to note, however, that particularly when doing temporal studies (i.e. comparing images from two different periods) or when working in a project areas near large bodies of water, it is essential that the imagery be radiometrically corrected from radiance values to reflectance values to assure proper comparisons and classification of the imagery.

Once the images are pre-processed, image processing techniques that are essential for successful interpretation of remotely sensed data can be initiated. These processing techniques can be divided into two types, image enhancements and image classification. The purpose of image enhancement techniques is to more effectively display data for visual interpretation (Lillesand and Kiefer 1994:525). Image enhancements include radiometric enhancement, spatial enhancement, and multiband enhancement (ERDAS 1994:145-146).

Radiometric enhancements increase the contrast of certain pixels at the expense of other pixels. This is achieved by altering the intensity value histogram of an image. Contrast stretching is one example. In this technique, the histogram is manipulated in a way to increase contrast between features of interest. This is useful because data rarely extends evenly over the entire intensity range. Thus, stretching the area of the histogram at areas of interests avoids crowding into a small range of display values (Lillesand and Kiefer 2000:493).

Another frequently used type of spatial enhancement are convolution filters, which involve the use of a matrix, or kernel, of varying dimensions that is used to manipulate the digital numbers of the imagery. The kernel is composed of a series of weights that is moved over the image gradually. When it does so, the kernel is multiplied by corresponding values in the image, their products are summed, and the new value replaces the digital number of the center element (Lillesand and Kiefer 2000:501). Low pass filters emphasize low frequencies and deemphasize high frequencies. Therefore, it has a smoothing effect on imagery. High pass filters, on the other hand, emphasize high frequencies and deemphasize low frequencies and thus produce a sharpening effect on imagery. It is important to note that image enhancement techniques like histograms stretching do not alter the digital numbers or brightness values of each cell in the raster grid. Filtering technique, however, do alter the BV and so complicate the temporal analysis of imagery particularly when comparing classes of features.

Another group of image enhancement techniques work on multiple images, often various bands of a multispectral digital sensor. The most basic of these is simply multiband viewing. Because the human eye is unable to see beyond the visible spectrum, imaging software allows bands to be assigned to red, green, or blue display colors. Moreover, each of these colors can be viewed simultaneously allowing multiband viewing.

Mathematical operations may be performed on bands of data. For example, subtraction, which reduces common details of bands and enhances contrast, is quite common (Showalter 1993:84). In fact, multiple operations are often performed. One commonly used example is the Normalized Difference Vegetation Index (NDVI), calculated by  $(\text{near IR} - \text{visible red}) / (\text{near IR} + \text{visible red})$ . NDVI is used for vegetation mapping and compensates for illumination conditions, slope, and aspect (Lillesand and Kiefer 2000:448).

Change detection is a specialized form of band mathematics that is used to determine differences between two images. In its most basic form, change detection can be accomplished by subtracting the values of a later image from an earlier image. Thus, higher values in the resultant image represent a greater amount of change. A more advanced form of change detection results in a thematic map that depicts regions of change beyond a certain threshold.

Other multiband image enhancements use statistical operations. One common and useful example is principal components analysis (PCA), which statistically removes redundancy that exists between bands (Lillesand and Kiefer 2000:518, Showalter 1993:84, Cox 1992:260). Here, the correlation between data bands is calculated and used to compress the data. The resultant data has fewer bands, but conveys the same information than the original. Thus, after PCA analysis, the bands are often simpler to interpret visually. Besides the use of PCA as an image enhancement, it is often commonly used as preprocessing to increase the efficiency of image classification and for removal of noise components from the imagery.

Image enhancements are designed to aid the user in pattern recognition. Image classification techniques accomplish this by using an automated process. Based on user-defined parameters, the image is partitioned into spectral classes. There are two types of classification, unsupervised and supervised, but hybrid techniques can also be used. These types are based on varying degrees of control in selecting the classes into which the image will be partitioned.

In unsupervised classification, the computer determines the classes after a number of parameters are chosen by the user. This process is performed by one of several clustering algorithms. One of the most popular is the ISODATA algorithm, which uses a minimum spectral distance to form clusters of data (ERDAS 1994:241). The ISODATA algorithm is iterative with an entire classification performed and new statistics calculated with each iteration.

In contrast, the significance of the classes is determined in the initial step of supervised classification. The user controls the classes that the image will be partitioned into by specifying training areas for each specific classification algorithm. Then, the machine classifies pixels into the specified classes that they most resemble.

#### GIS and remote sensing ANALYSIS

Geographic information systems manage location and attribute data (Lillesand and Kiefer 1994:39). A GIS often includes vector data composed of point, line, and polygon features. These features are linked to a database that may include any of several types of attribute data. The matrix form of raster data can also be included in a GIS. For remotely sensed data, each cell in the matrix contains a reflectance value corresponding to some ground area.

An important use for a GIS is the analysis of multiple data layers. When registered in a common grid system, diverse data sets, including airborne remote sensing and near surface geophysics, may be compared and analyzed. Supplementary data, such as historic maps, plats, and other spatial documents may be overlaid with the raster imagery. Other types of data may also be overlaid in vector format.

The precision georeferencing, or assigning map coordinates, to data layers is very significant. Often this is accomplished by referencing one type of digital data to another with a known grid system. This process requires both patience and a good eye for common features. Various rectification algorithms are used then to resample a data set to the new grid system. For imagery with little distortion, a simple first order polynomial may be used, which only requires three ground control points. For more distorted imagery, higher order polynomials must be used. However, in cases of complex, nonlinear distortions, a rubber sheeting model must be used.

There are several ways that the analysis of remote imagery and other data layers in a GIS might benefit cultural resource projects. For example, advanced knowledge of terrain features and land cover can assist in the formulation of survey methodology. The total acreage of wetlands, forests, open field, and other ground cover types in the project area can be determined and a plan devised. When arduous field conditions make standard survey methods difficult, such as the coastal wetlands are fairly inaccessible. It can help determine the mode of transportation that will be required and

where crews can be dropped off and picked up. Transects can be laid out in advance of a survey as a GIS layer and accurate field positions can be maintained with total station or GPS units. Parcels of land representative of various terrains in the project area can be measured rapidly from digital imagery and quantitative and statistically representative samples can be determined prior to the crews entering the field. The use of remote sensing as a component of the fieldwork in these areas most is likely to yield positive results. Another situation when remote sensing is a reasonable option is when time in the field is constrained. Although standard survey techniques are inexpensive, they can be very time consuming. Again, remote sensing can help make the best of a short field season. Analytically, the landscape classification potential of digital remote sensing data provides information on land cover/ land use changes; alternative location of developments; high probability areas for stratified sampling strategies. Finally, remote sensing may be appropriate if there is a long-term research commitment to a particular region. The initial investment in a digital product can provide returns over many seasons of fieldwork. In short, , with improved and more accessible technology and sound methods, remote sensing can be a valuable tool for archaeological research.

## SOURCES OF REMOTE IMAGERY

There are several ways that remote imagery might be acquired by cultural resource managers, including finding existing imagery, hiring someone, or produce imagery in house (Ebert 1984:304). Black and white aerial photography covering most areas of the U.S. may be acquired from archives and are increasingly available online for very little charge. An example is Digital Orthophoto Quarter Quads (DOQQs) produced by the United States Geological Survey's National Aerial Photography Program (NAPP). These are 1-meter images that are typically in black and white form, but are in color infrared for select areas. For example, DOQQs for the entire state of Mississippi are available for free download from the Mississippi Automated Resource Information System (MARIS) website.

Another example is aerial photographs produced by the Soil Conservation Service and the United States Geological Survey. These are often purchased inexpensively as hard copy photographs, but can be converted to digital form with a high resolution scanner. One advantage of these images is that they may be available for multiple years dating back as far as the 1930s. Older photographs may provide information that has been lost due to damage from agriculture or other cultural disturbances.

Multispectral imagery is now available for very little cost in online archives. The most prolific of these is Landsat imagery, which may be purchased on line from the EROS Data Center operated by the USGS. A total of six Landsat satellites have been in operation from the early seventies until today, allowing a near continuous temporal coverage of most areas. A number of sensors have been carried on the various Landsat satellites, but they have generally produced fairly medium resolution imagery recorded in broad bands. For example, the most recent of these is the Enhanced Thematic Mapper Plus (ETM+) aboard Landsat 7, produces one 15 meter panchromatic band, six 30 meter multispectral bands from visible to mid-infrared, and one 60 meter thermal infrared band. Landsat, can be ideal for predictive modeling on regional scales. Similar imagery from other numerous other satellite sensors, including NASA's ASTER and MODIS, EO-1, and NOAA's AVHRR, is also available from the EROS Data Center site and from data archives searchable over the Internet.

Commercial satellites imagery has become more common and often achieves much higher spatial resolution than Landsat. One example is the series of Ikonos satellites operated by Space

Imaging, which may be purchased as Carterra digital products. The newest of the Ikonos sensor produces imagery 1 meter panchromatic and 4 meter multispectral ground resolution. Multispectral imagery contains relatively broad near-infrared, red, green, and blue bands. The Quickbird sensors are another of the new generation of high-resolution satellite sensors. They offer spatial resolutions as high as 50 centimeters and bands comparable to the Ikonos satellites. The drawback of the newer high-resolution satellite sensors is that the imagery is relatively expensive to obtain. One can possibly reduce costs by using the high-spatial imagery to subsample statistically relevant sections of larger survey areas or lower resolution imagery.

Remote imagery may also be obtained by contracting an outside company to conduct a flyover. There are many private companies today that can be hired to acquire remote imagery for particular projects. These are typically very high quality, but may be quite expensive. Using an airborne platform one can control the temporal resolution of the mission. Also one can fly at attitudes that provide various spatial resolutions from sub-meter to dozens of meters. And the spectral resolution of airborne sensors is now very advanced. Fairly inexpensive multispectral or even hyperspectral imagery can be collected from fixed wing aircraft using three or more co-registered digital cameras with CCD arrays and specified interference filters. It is important to understand the spectral response pattern of the features of interest prior to selecting the filters.

In order for archaeologists to produce their own aerial imagery, a substantial commitment is usually required in terms of the purchase of equipment. Necessary equipment primarily consists of a sensor and some platform. The sensor may range from standard 35mm film cameras to low cost multispectral cameras. Three band multispectral cameras designed for agricultural applications are now available for several thousand dollars or less. Thermal infrared cameras have traditionally been more expensive, but are quickly becoming affordable. The platform may be a kite, balloon, unmanned aerial vehicle (UAV), or a manned aircraft such as a powered parachute or Cessna. Flyovers may be also arranged with local private pilots on aircrafts, but, over time, this is usually more expensive. Although imagery may be of somewhat less quality, this method allows the archaeologist greater control over data collection.

## INTEGRATING REMOTE SENSING INTO CULTURAL RESOURCE MANAGEMENT PROJECTS

Remote sensing can be useful in cultural resource management projects in several fairly different ways. Because these applications are diverse, good planning is necessary to integrate remote sensing into a research design. With foresight, it can be used to address a variety of problems in a standard three-phase CRM approach, increasing both their efficiency and quality. Applications can be broadly grouped into three categories: predictive modeling, site detection, and site mapping.

Predictive modeling of archaeological sites attempts to connect site location with modern environmental patterning. Although the landscape has, in many cases, changed greatly, large-scale ecological features often remain in place. Analysis of medium-resolution multispectral data, such as that produced by the Landsat satellites has been demonstrated to be a useful technique in rapidly mapping land cover. Digital data can be manipulated and themes or classes of phenomena on the earth's surface extracted. Using a GIS, a statistical model can be constructed by comparing known site locations to the environmental zones that have been produced. Predictive modeling is a way to reduce the amount of land included in a survey area and can be useful in the planning stage of cultural resource surveys. A predictive model is never able to account for the location of all sites,

but can be beneficial in identifying high probability survey areas.

Remote sensing using airborne and orbiting instruments is a useful approach particularly for the detection of sites in Phase I (scoping and surveying) aspects of CRM work as required under the National Environmental Policy Act of 1969 (NEPA) Section 101 (b)4. Site locations may be apparent as lineaments or regularly shaped anomalies in the imagery caused by topographic variations, soil marks, or vegetation marks. Site boundaries may be established by determining the extent of these anomalies. The British have extensively used aerial reconnaissance for site detection, in part because of favorable ground cover conditions. However, due to recent developments in recent sensing technology, it should also be seen as viable site detection tool in many areas of North America in.

Site mapping is often performed in Phase II site assessment or in Phase III data recovery stages of a CRM project. The mapping of features within a known site can sometimes be accomplished using remotely sensed data. Often, these are subsurface features that are otherwise invisible in ground observations, but are visible as subtle variations in electromagnetic energy at the surface of the Earth. These are primarily visible as soil or vegetation marks caused by the underlying archaeological resources.

Throughout a CRM project, data analysis may be aided with the use of remote sensing and GIS techniques. The digital products created during this approach serve as layers in GIS. Co-registration of modern imagery with historic maps, plats, and surveys provides useful information about the location of historic properties.

## PREVIOUS WORK

The literature has traditionally been dominated by applications in Britain, where conditions are particularly favorable for success. One representative example is offered by Featherstone et al. (1996), which describes a large-scale site survey conducted in England by the Royal Commission of Historical Monuments of England. Conducted during a particularly dry summer, approximately 415 flight hours were logged spanning a large portion of England and Scotland. The program was focused both on site detection of unknown cultural resources and intrasite mapping of known resources. A total of 4570 targets were photographed and identified in crop marks, with about half representing unknown sites and 15 percent contributing new information to known sites. Sites detected included Bronze Age barrows, causeways, Iron Age enclosures, Roman field systems, Roman road systems, Neolithic mortuary enclosures, henges, ring ditches, hill forts, barrows, fortresses, and earthworks. These cover a multitude of construction types and time periods. The productivity of the project was extremely high. For example, in northern England, 79.2 hours of reconnaissance produced 1018 sites or an average of 12.8 sites per hour. Many of these were previously unrecorded and additional information was added for many others.

Although not nearly as routine as in Great Britain, aerial reconnaissance has also been employed in the United States. One example is presented by Lyons and Hitchcock (1977) and involves the analysis of an Anasazi road network. Lineaments within New Mexico's Chaco Canyon had been first noticed on early Soil Conservation Service photographs in the late 1940s. To determine the arrangement of these anomalies, additional black and white photography was acquired. An extensive network of the lineaments in excess of 250 miles in length was mapped. Investigation found these were visible for several reasons, including decreased vegetation, increased vegetation, topographic change, and differential moisture. Association with known Anasazi settlements has suggested these made up a road system dating from the Pueblo III period.

Site detection and mapping applications in the Eastern Woodlands, however, are particularly hindered by the type of ground cover and more frequent historic alterations (Johnson et al. 1988:124). Nonetheless, some successful applications have been conducted. Continuing work at Cahokia is one example. Oblique photographs produced by Goddard and Ramey were acquired as early as 1922. The photos contain a substantial amount of information about the structure of the site and are still a valuable source of information today (Fowler 1977:65). Fowler (1977) presents an analysis of this and more recent aerial reconnaissance at the site and was able to reveal the location of destroyed mounds, a palisade line, and numerous subsurface features. In addition, they were used to quickly and efficiently create a base map of the site.

Another excellent example is O'Brien's (O'Brien et al. 1982) use of aerial photography and image processing to detect house patterns at a large Mississippian site in Missouri. The Common Field Site is a large 17-ha fortified Mississippian center in the Central Mississippi River Valley. A significant amount of topsoil had been removed by flooding in 1979, which exposed numerous features. An aerial campaign was undertaken that included stereo black and white photographs and color-infrared photographs. These were scanned into digital format so that they could be enhanced via digital image processing techniques. Significant variation in soil moisture was, however, found to be problematic. To remedy this situation, histogram equalization and interactive gray-level slicing was performed. This process was found to substantially enhance the house patterns in the imagery.

Thiessen (1993) describes mapping of archaeological resources in the Knife River region of Minnesota and North Dakota by the National Park Service. An array of photographic sources, dating from 1938 to 1976, was used. These include several sets of vertical black and white photographs, black and white oblique photographs, and color infrared photographs. In several photographs, anomalies thought to be lodge depressions were detected. These were found to have been produced by slight topographic variations and, in one case, were highlighted by snow.

Another effort (W. Johnson 1994) identified new earthworks and borrows along the Kissimmee River using early aerial photography. This research was a part of a regional aerial survey that yielded 38 previously unrecorded sites and additional information on 9 sites in the West Okeechobee Basin. The earthworks located along the Kissimmee River are primarily composed of geometrically or anthropomorphically shaped ditches and embankments that may be associated with mounds. The aerial photographs revealed information about the shape of the earthworks in addition to new features. Based on the regional distribution of these shapes, Johnson uses the data to support a Belle Glade culture origin of the earthworks. This work also illustrates an additional application of aerial photography. Disturbances due to modern human activities can be better evaluated by studying a series of photographs taken over many years. This information may be useful for archaeological preservation efforts.

Carskadden (1999) describes an application of black and white aerial photography in mapping late Adena and early Hopewell earthworks at the Gilbert site in Muskingum County, Ohio. Most of the earthworks were destroyed as a result of agriculture and other modern activities and are not visible from the ground. Based on early maps, the earthworks consisted of parallel walls, a "D" shaped enclosure, two sacred circles, two rectangular enclosures, and a number of mounds. From the aerial photographs, which were produced in 1950 by the Department of Agriculture, the author was able to generate a basic map of these features. Unknown features associated with the complex were also discovered, including a gateway in one rectangular enclosure and a small mound within the other rectangular enclosure.

Remote sensing covering the spectrum beyond visible energy has significantly contributed to archaeological research also. One well-known example in Central America is the detection of

footpaths in the Arenal region of Costa Rica with color infrared photography (Sheets and Sever 1991, McKee, Sever, and Sheets 1994, McKee and Sever 1994). The footpaths were first detected as a set of lineaments in 1985 during analysis of a set of color infrared photographs acquired by NASA. The anomalies were primarily visible as positive vegetation marks in grassy ground cover. Because they tend to follow ridge tops and because of their relationship to known sites in the region, the anomalies were interpreted as prehistoric footpaths. Further analysis in the form of excavation trenches produced ceramic and lithic material that confirmed the paths were of a prehistoric origin. Although the paths are often visible on the ground as erosional features, airborne imagery made mapping much more efficient.

One application of color infrared photography in the Southeast focused on the Fort Mims Site in Alabama (Riccio and Gazzler 1974). Specifically, research sought the location of two large burial pits, which were believed to be the result of a Creek Indian massacre in 1813. Other methods, included soil resistivity, had failed to locate the targets. Color infrared photographs were produced during flights in 1972 and 1973. During analysis, two anomalies were identified that fit with historic accounts of the events. These were located in a pasture area of the site. Ground truth consisted only of two corings in the anomalies. Although no burial materials were found, it was confirmed that the anomalies were indeed pit features.

An example of the use of aerial photography in Mississippi is North and Svehlak (1977). This work describes aerial reconnaissance at the Fatherland site, also known as the Grand Village of the Natchez. A plan was drawn up to uncover and restore the village so that it could be opened as a historic attraction. As part of this program, panchromatic infrared photographs were produced of the site in 1972. Upon analysis, two obvious anomalies were detected. Based on subsequent excavation data, the anomalies were interpreted as fenced compound and sacred garden. Another anomaly was visible that might have been the remains of a structure, but it was not ground truthed. In addition, the probable location of Fort Dearborn, a French fort contemporary with Fatherland, was determined.

Davidson and Hughes (1986) describe an effort to detect the Nanticoke village of Chicone in eastern Maryland. At the time of contact by the British, the Nanticoke made up a powerful and prosperous chiefdom, whose capital was the village of Chicone. The location of Chicone was described in several 17<sup>th</sup> and 18<sup>th</sup> century documents, but finding archaeological evidence has been difficult. From 1980 to 1983, an aerial survey of the Nanticoke reservation was conducted to locate the village. Both color and color infrared photographs were acquired from an oblique perspective several times each year. Crop marks, most prominent in late summer and early fall, and soil marks, most prominent in the winter, showed linear, rectangular, circular, and doughnut-shaped anomalies concentrated near the Chicone River. Accounts indicate the doughnut-shaped anomaly is similar in size and form to the village. Excavation revealed that the anomaly was a ditch that surrounded organic soils. Nanticoke ceramics and lithics dated from the late Prehistoric and early Historic periods. European tobacco pipes, gunflints, and glass trade beads were also found. Thus, the doughnut-shaped anomaly did indeed fit the description of Chicone village.

The development of digital multispectral sensors and their ability to reveal more information about ground targets has allowed archaeologists to use remote sensing in new ways. Custer et al. (1986) is the work that set the precedent for predictive modeling using multispectral digital data. Here, environmental zones were determined for a 292 square kilometer area in the Delaware Coastal Plain by performing supervised classification on Landsat data. Using logistic regression, a quantitative measure of the likelihood that a zone contains a site was found. Once this was determined, the probability that an unsurveyed area contained sites could be found once it was

assigned a class. This work had important implications for the regional management of archaeological resources and survey design methods.

One of the most successful applications of remote sensing in eastern archaeology was in Delaware during the early 1980s. In this study, Custer et al. classified a large portion of central Delaware into broad land cover and hydrological classes using Landsat Multispectral Scanner imagery. They found that these modern land use classes were correlated with edaphic factors known to influence prehistoric settlement choices. For example, high productivity farmland is correlated with well-drained soils, whereas wooded areas generally occur on poorly drained soils. Given this base map, Custer et al. were able to statistically characterize the distribution of known sites in relation to these major land and water classes. The settlement model derived from this exercise proved to be over 90% accurate in predicting site locations in unsurveyed areas.

In the late 1980s, Johnson et al. conducted a similar project in north Mississippi. Landsat Thematic Mapper data classified and statistical tests were performed to determine how the land cover related to site location. However, the results of this effort were more modest, because Johnson et al. found that modern land use classes were less strongly correlated with the primary physiographic zones in the region.

Limp (1993?) reports on two studies in Arkansas using French SPOT images. SPOT provides three digital bands in the green, red, and near infrared part of the electromagnetic spectrum, at a ground resolution of 20 meters. In the first effort, Limp performed an unsupervised classification of the landscape surrounding Frog Bayou using the instrument's three digital bands. Limp then overlaid known site locations on the classified image. He reports that three spectral classes, representing 30% of the surface area, overlaid 50% of the site surface area. In a similar study at Lee Creek Valley in western Arkansas, Limp classified a SPOT image into 23 classes. In this case, three of those classes account for 17% of the ground area, but 37% of the site area with midden, and over 60% of the Mississippian site area. However, Limp indicates that these three spectral classes are not directly related to the sites themselves, but appear to reflect agricultural practices in the region. He therefore suggests that the classes provide indirect predictors for site locations.

Johnson (1991 [1990?]) describes his efforts to identify "site-specific [spectral] signatures" in Thermal Infrared Multispectral Scanner imagery. Johnson acquired a 12 kilometer line of NASA's thermal sensors (TIMS, Thermal Infrared Multispectral Scanner) data at 5 meter ground resolution over the same region of northern Mississippi previously studied with Thematic Mapper imagery. TIMS acquires six narrow bands of data covering the thermal infrared portion of the electromagnetic spectrum and is capable of discerning differences in temperature of .3 degrees C or less. Johnson first performed an unsupervised classification of the TIMS image and compared the resulting classes with the distribution of known sites in the region. This initial analysis revealed no correlation between the unsupervised spectral classes and the sites. In a second effort, Johnson performed a supervised classification on the TIMS image, using large midden areas of the Mississippian Lyons Bluff site as his training sets. However, the spectral signatures derived from these training sets also proved to be poor predictors of site locations in other parts of the image.

The use of imagery with higher spatial resolution has allowed for attempts to directly detect archaeological features. A follow-up to the 1977 Chaco Canyon roadway system mapping project was performed by Sever and Wagner (1991). The more recent study used TIMS and another airborne sensor, the Thematic Mapper Simulator (TMS), which duplicates the channels of Landsat TM. Both types of imagery were enhanced using high and low pass spatial filtering. This revealed linear and curvilinear patterns, particularly in the TIMS data that corresponded to the roadways. Also, prehistoric field boundaries could be defined. Overall the narrow thermal bands of the TIMS was more useful than the TMS in this example.



The Arenal Project in Costa Rica referenced above, used a variety of sensors to detect prehistoric footpaths. The footpaths, which are erosional features, were clearly visible in the TIMS thermal imagery in addition to the CIR, color, and black and white photographs. A network of the footpaths was revealed that connected sites across a large region. Subsequent excavation confirmed that these were indeed cultural features formed before European contact.

A number of projects have been conducted that focus specifically on the use of thermal sensors for archaeological prospecting. An early application of thermal scanners was Berlin's (Berlin et al. 1975, Berlin 1977) use of detection of a prehistoric agriculture system in the Southwest. A broad-range thermal radiometer, sensitive from 8  $\mu\text{m}$  to 14  $\mu\text{m}$ , was used to generate thermograms for an area of Arizona in April 1966. Anomalies in the imagery were interpreted as prehistoric agricultural plots. They were not visible on black and white aerial photographs. The agricultural plots were made up of a series ridges and swales. Ridges were capped by a later of basaltic ash, while the swales large exposed buff soil areas. A 24 hours temperature history revealed the higher thermal diffusivity of the ridges caused them to heat faster than swales. Maximum temperature differences were between 1.1 degrees to 6.2 degrees. Based on nearby excavations, the features were found to be of Sinagua origin, dating from about 1150 A.D.

Sever (1985) and Gibson (1987) describe an effort to use the Thermal Infrared Multispectral Sensor (TIMS) at the Late Archaic Poverty Point site in eastern Louisiana. At the altitude flown, the ground resolution of the imagery was 5 meters. Based on later ground truthing, anomalies in the thermal data were caused by barrow pits, fill episodes, a ramp, and a corridor. In addition, several areas of the site's concentric rings were highlighted. However, several other anomalies turned were later determined to be of historic origin.

Sever has also applied the TIMS sensor to the detection of roads and subsurface features in Chaco Canyon. This work is described in Sever and Wiseman (1985) and Sever and Wiseman (1991). From the TIMS imagery, a number of Anasazi roadway sections, invisible both from the ground and in color infrared photography, were identified. Also, subterranean walls, agricultural fields, and the location of several sites were determined. Image processing techniques in the form of high pass Gaussian filters were used to enhance the data. Several potential factors are cited as being sources that made these features visible in the TIMS imagery. These include disturbances in soil texture, changes in microtopography, and changes in soil moisture.

## GROUND TRUTH

In most cases, deriving the correct from the analysis of remotely sensed data requires some ground verification data. Spatial and spectral in-situ data is required to georeference or register imagery and to identify the spectral signatures of specific features. Visual identification of vegetation and other features made on the ground is often the best and simplest method to "train" classification algorithm used if supervised classifications of imagery.

Spatial ground truth data is normally collected using GPS equipment. For proper registration of high-spatial resolution imagery, accurate GPS locations, to within the IFOV or pixel size of the imagery should be collected using differential GPS. Since the Federal Government ceased to scramble GPS signals, the ability of most GPS units to provide locations accurate within a meter or so has been highly enhanced.

Spectral ground truth data is collected with spectral radiometers that can be hand-held or suspended a few meters above the feature. Spectroradiometer collect energy from the relevant feature along either broad or narrow bands. Since these readings are being collected close to the object, the radiant flux or energy contributed to airborne and satellite imagery by atmospheric

scattering of light or from pixels adjacent to the pixel of interest, is minimized or eliminated. Collected spectral readings enable the remote sensing analyst to radiometrically correct satellite and airborne imagery.

Often large placards of known spectral reflectance (large gray scales visible by the airborne sensor) are located along a flight path to allow comparison of the known reflectance with the radiance collected by the sensor over the placard. The difference between these two values can be subtracted from the entire image to produce radiometrically corrected data.

## CASE STUDIES

An example of using airborne imagery to map subsurface archaeological features is the research conducted at the Hollywood site by the University of Mississippi (Johnson et al 2000, Haley 2002). Hollywood is a late Mississippian site located in the northwest Mississippi a short distance from the modern channel of the Mississippi River. The site contains at least five mounds that are still visible today despite the impact of a century of agricultural activities. A sketch map (figure 4) produced by Calvin Brown in 1923 shows a series of perimeter mounds that are no longer visible today. In order to locate some of these lost features, the site has been imaged by several geophysical techniques and numerous types of airborne remote sensing.

Black and white Soil Conservation Service photographs were acquired for the years of 1938, 1942, 1966, and 1992 (figure 5). These were scanned using a high resolution scanner and georeferenced to the site grid system. One valuable aspect of this set of photographs is that they document some of the historic activities that have impacted the site. For example, visible in the earliest two photographs are historic structures atop two of the mounds. In addition, numerous high reflectance patterns are visible in the 1938, 1942, and 1992 photographs in the northern half of the field. These patterns were probably caused by differential vegetation growth, drying variations, or, in the earliest two images, topographic change. Geophysical surveys conducted by Berle Clay in 1998 and excavation by the University of Mississippi in the years that followed revealed the buried remnants of Mississippian houses in these areas (figure 6). In the 1992 photograph alone, another feature of interest is visible in the southern half of the field. This arc of low reflectance is very similar to the perimeter mounds visible in Brown's sketch map. Moreover, it is not caused by modern topographic change.

Similar patterns are also somewhat visible in large format, color infrared photographs acquired with a Zeiss camera system by NASA in 1997 (figure 7). Large format cameras produce photographs of exceptional sharpness and definition (Riley 1987:55). For Hollywood, they were scanned to produce a digital image with a ground resolution of 39 centimeters. Once in digital format, the area of interest was subsetting and contrast enhancement performed. The resulting image contains much clearer versions of the anomalies.

The same mission also carried the ATLAS sensor, which acquired multispectral imagery at a ground resolution of 2.5 meters. ATLAS produces 15 bands of data, including 6 in the reflected range, 2 in the mid-infrared range, and 6 in the thermal infrared range. An image acquired at about noon shows the same high reflectance patterns in reflected energy bands, particularly the near infrared (figure 8).

The thermal infrared bands of the ATLAS sensor contain some different anomalies. Several low emittance ellipses just to the west of the tree covered mound A seem to correspond to some of the perimeter mounds. The fill that makes up these mounds contrasts with the surrounding soil,

which altered their physical properties and affected their diurnal heating cycle. Also visible in the ATLAS thermal infrared is an artificial plaza area to Mound A. Other anomalies are suggestive of past cultural activity, but have not been ground truthed.

Targeted thermal reconnaissance was also performed by the University of Mississippi by suspending a hand-held Agema 570 thermal camera from a helium blimp (figure 9). Three houses and one of the mound patterns were targeted over a six month period in 1999. The three houses are situated in differing soil matrices ranging from clays to sandy natural levee and thus the thermal behavior of these features varied. Overall, the clearest of the anomalies were produced by the houses situated in the finer grained soils at the site (figure 10). In these night time images, the houses produce cool anomalies, suggesting they have higher thermal inertia values than the surrounding soils. The truncated mound was not apparent in the imagery. However, this may be due to the small scene size of the images and the large size of the feature.

## CONCLUSIONS

Remote sensing using airborne and satellite imagery is particularly useful during Phase I CRM work. When properly pre-processed and processed, the imagery serves as planning tools for conducting surveys, including drawing statistically significant samples for random, systematic and stratified survey strategies. The samples can be drawn both on the basis of the spatial and the spectral attributes of digital data. As a consequence of registering or rectifying an image to a map, the image becomes an accurate map of the project area from which statistically significant samples can be extracted and located in the field.

Similarly, after the image has been radiometrically corrected, thematic classification of biophysical features such as vegetation and soils can provide a sound basis for extracting stratified samples that emphasize areas of high site probability, particularly when sampling various ecosystems.

When modern imagery is registered to historic maps and plats, the search for structures and features identified on the original documents becomes more effective and less costly. Survey teams should be able to narrow the size of any particular area to be searched. Furthermore, the current land cover classes extracted from modern imagery can provide important information on the probability of finding historic sites. For example, the severity of any river channel migration can be assessed by comparing modern imagery and historic maps to rapidly assess whether a particular site has been irrevocably eroded since its establishment.

Satellite and airborne imagery, including updated DOQ and DOQQ, serve as useful strategic tools to assess the survey methodology of any particular CRM Phase I study. A rapid examination of the survey area using remote sensing data can assist the project manager in determining access to the survey site, the size of the required survey crews, the possible spacing of transect lines, the equipment required and the amount of surface visible in any particular area.

Under the best conditions, passive remote sensing acquired from aircrafts and satellites serves to discover sites, delineate their extent and accurately map their features. Conducting spectral analysis of well-calibrated digital data using pre-determined spectral bands has identified trenches, moats, wells, earthworks, pits and organic soils. Hyperspectral data holds great promise for refining the use of crop marks for identifying sub-surface deposits. Plants may show added vigor as a result of organic matter or, conversely, show stunting due to the hard substrate that hinders root growth. Modern digital imagery filtered by narrow band spectral interference lenses advance this traditional method of site identification.

Federal Distributed Active Archive Centers (or DAACs) provide greater access to digital remote sensing data often at nominal costs. In addition, agencies like the USGS provide digital line graphs (DLG) and digital elevation models (DEMs) available on CDs or through direct downloading over the Internet. These data are excellent for registering images to maps and therefore deriving planimetrically accurate products to a variety of scales and projections. Commercial firms that operate satellite and aircraft for collecting remote sensing data are much more common and becoming more affordable, particularly once the spectral response curves of specific features of interest have been identified in the laboratory allowing the proper choice of spectral filters for CCD cameras that can be mounted on inexpensive platforms such as fixed winged aircrafts, blimps or large kites.

Technology has improved significantly the tools available to even the most sophisticated remote sensing data processing and analysis. In just the last five to ten years, computers have been created with vastly improved RAM, storage and speed, making the use of laptops and desktops for image processing a very viable alternative. Advancement in hardware has been matched by similar progress in remote sensing and GIS software. Window-based systems, with simple GUI interfaces and drop-down menus provide even the beginning analyst with all the pre-processing and processing tools to derive planimetric and thematic information from all types of digital remote sensing data.

In summary, remote sensing data from airborne and orbiting platforms can save significant resources during all aspects of CRM, particularly in Phase I surveys. Even more importantly, these data improve the accuracy and thoroughness of surveys, particularly those conducted in relatively inaccessible areas like coastal wetlands and marshes.

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